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INFORMATION SHEET ON BIN-TYPE FINISHING DRIERS IN VEGETABLE DEHYDRATION

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The bin finisher provides an efficient, relatively inexpensive means of finally drying vegetables to low moisture content. It is compact and has a comparatively high heat use. If it is used as final drier, better use can be made of the preceding dehydrator, whether it is a tunnel, cabinet, or belt type. All of these types use large areas of loading space for the reduced volume of thinly spread, partially dried product.

If a bin drier is added to a system and, further, if additional heat-generating capacity is available in the preceding drier, then the plant capacity is potentially increased. The shortened retention time required by the preceding driers in reducing the moisture of the product to a condition satisfactory for bin drying (approximately 10 to 15 percent moisture) permits the system to handle additional tonnage, which of course requires additional heat.

Very little is known of the performance characteristics of bin driers. Their use as an expedient for increasing plant output or for carrying the dryness of the product to low-moisture limits is, however, of unquestionable value. As a secondary aid, the bin driers can be used to supplement the plant's finished product storage facilities. Being relatively simple and easy to build and operate, finishing-driers are becoming standard equipment in most dehydrating plants.

Types of Bin Driers

There are two basic types of bin driers--the batch-process bin drier and the continuous bin drier. These units are sometimes called bin finishers. The continuous bin drier usually consists of a single unit, whereas the batch-process drier is almost invariably a multi-bin drier or multi-bin finisher.

The continuous bin finisher, because of its operating characteristics and its size limitations, is generally confined to use in small plants. The unit consists of a large storage bin designed for working depths ranging approximately from 3 to 8 feet. Drying air is introduced through louvers at or near the bottom of the bin. The bin must be of air-tight construction except for an exhaust port located in the top or at some other position above the active bin level. A gate is provided in the bottom of the bin to permit gravitational removal of the product in progressive layers. To facilitate removal and to prevent arching, mechanical or electrical agitating or shaking devices are sometimes provided. Figure 1 shows a typical design for a continuous bin finisher intended for use with onions. Note the location of the agitator.

When the bin is in operation, the partially dried material is allowed to enter in a steady stream, at such a rate that it keeps the bin completely filled. A draft of heated dry air is forced through the louver inlets at the bottom and the product dries progressively upward; therefore, the dried product at the bottom is removed at the same rate as the bin is loaded from the top.

The batch-process bin finisher is somewhat similar in design. A gate is located at the bottom to permit dumping of the entire bin. Three or more bins are usually required, as will be explained later. In operation, the entire bin in filled with the partially dried product; the material dries progressively upward, and, as soon as the material near the top is dried to the required moisture content, the entire bin is dumped and a new cycle is commenced.

Operation of Bin Driers

During normal operation, the product, as loaded into the bin drier, contains not over 15 percent moisture. This partially dried product is of sufficient stiffness so that it will not crush, and will form a solid mat. Therefore care should be taken not to tamp the product during loading operations. The charging depth may vary between 3 and 6 feet. Under this condition of loading, air can be readily forced through the material by standard-design blowers.

As a product loses its moisture, its rate of drying becomes slower and slower. The latent heat necessary for evaporation will be required at a proportionally slower rate. Since the air is the source of heat supply and transfer medium, the required quantity and velocity of air become correspondingly smaller. The air bathes the product and carries away the diffused moisture as it is released. 1/

The depth of bed will determine to a large degree the batch retention time. Usually bins are operated at the upper limit of the usable temperature range. If excessive bed depths are used, the dried product on the bottom may be injured by prolonged exposure to maximum temperature. Therefore, to reduce the batch-retention time, relatively high velocities should be used.

An undesirable condition that may arise is illustrated by the following example: Let us assume that a deep-bed bin drier is being used to finish potatoes. Assume further that the potatoes have been scraped from drying trays of the preceding stage in a room having a temperature of 60° F. It is probable, then, that when the bin is filled with these potatoes, the average bin temperature will be in the neighborhood of 60° F. Assume that air at a relatively low velocity and temperature is circulated through this bed. The air will pick up moisture and gradually drop in temperature until, at a certain point in the bed it can no

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1/ The principles involved are discussed in the following articles: Furnas: Heat transfer from a gas stream to a bed of broken solids, Indus. and Engin. Chem. 22:721-731 (1930); Gamson, Thodos, and Hougen: Heat, mass, and momentum transfer in the flow of gas through granular solids, Trans. Amer. Inst. Chem. Engin. 39:1-35 (1943).

longer dry the product. From this point, the cool product will gradually reduce the air dry-bulb temperature until, at a point within the bed, the air becomes saturated. Further penetration of the air, while in contact with the cold bed, will reduce the air temperature below the dewpoint; thus moisture will be condensed upon the product. If this condition arises, the wetted product may be injured. The condition can be remedied by increasing either the temperature or the velocity or both, by decreasing the bed depth, or by providing auxiliary internal bin-heating devices.

An operator can detect faulty bin operation by taking samples from the uppermost surface of the product periodically throughout the drying cycle and analyzing them for moisture content. The time intervals should be fairly close because the region of condensation, which is likely to be fairly shallow in depth, might otherwise not be detected.

Regardless of the velocity and temperature of air employed, a bin drier will ultimately carry the product through the full depth of the bed to a condition approximating equilibrium with the entering air. This, of course, is based on the assumption that heat loss due to radiation, convection, and conduction from the outer surfaces of the bin are relatively small.

Batch drying is intermittent in operation; therefore several bins are usually required to provide continuous operations. At least three bins are usually employed; thus loading, drying, and unloading can be carried on simultaneously. Figure 2 shows a suitable multi-bin finisher design. Any number of units in addition to the three shown can be provided to suit plant capacity.

Determining Needed Capacity

To illustrate a method of determining required capacity, we may consider a small onion-drying plant producing approximately 225 pounds of flaked onion per hour. Laboratory tests indicate that a 5-foot depth of product can be dried from 12 to 4 percent moisture in approximately 8 hours. The plant will accommodate a bin not over 10 feet wide. What should be the bin proportions?

The bulk density of nearly dried flaked onions is found to be approximately 15 pounds per cubic foot. Since one continuous bin is to be installed, it must have sufficient volume to accommodate the entire output of the plant for an 8-hour period. Its capacity can be computed by multiplying the retention time in hours by the plant output per hour and dividing by the bulk density of the product. Thus the volume of the bin equals 8 x 225/15 or 136 cubic feet. With a bed depth of 5 feet, the cross section of the bin must be slightly over 27 square feet. Since the bin is to fit into a 10-foot-wide space, a bin 4 x 7 x 5 feet may be satisfactory.

Let us suppose that a unit of this size has been built, and that subsequent tests show that the 8-hour drying time is too short. If the highest permissible air temperature for drying onions is already in use, the bin capacity can

be further increased by resorting to higher air velocities. If, however, the fan is operating at full capacity, the only remaining alterable condition is to reduce the moisture of the entering product by increasing the retention time in the preceding stages.

Increased drying in the preceding stage affects the bin capacity in one of two ways. First, the longer retention period in the preceding stage decreases the input to the bin drier. Second, the reduction in total moisture to be removed by the bin drier shortens retention time here. Hence, under a particular ratio of primary to secondary retention time, a balance will be reached. Although predictable with a fair degree of accuracy, the optimum ratio can best be found by trial and error.

The balance established under one set of drying condtions will not necessarily hold for all other drying conditions. For example, the operating balance established with day-time initial drying and night-time bin drying may not be suitable if the drying cycle is reversed. This change in retention ratio from day to day is obviously undesirable. However, a safe working ratio can be established, based on the most unfavorable conditions, and thus a workable solution can be obtained. The effect is to produce extra drying some of the time. However, the ease of operation on a fixed schedule will in all probability offset the expense of the additional heat. The loss of product weight due to extra drying will be negligible.

As an example of multi-bin driers, let us assume that the management of a medium-sized plant is considering the installation of a multi-bin finisher to increase the plant capacity. The plant is to be able to process 300 pounds of potatoes per hour, having a moisture content of 12 percent. Packaging is to be done only during one 8-hour shift. How large a multi-bin finisher will this plant require?

The bulk density of partially dried potatoes is found to be 15 pounds per cubic foot. Material will then be delivered to the bins at a rate of 300/15 or 20 cubic feet per hour, or 160 cubic feet per shift. Assume that previous experience indicates that 12 hours are required to reduce the moisture content of potatoes from 12 to $4\frac{1}{2}$ percent. The bins, therefore, must have a minimum total volume of 12 x 20 or 240 cubic feet if packaging operations are to be continuous. The bins selected for use are to have a working volume of 80 cubic feet. The minimum number of bins required would then be 240/80 or 3 bins. However, since the product is to be packaged only during the 8-hour-day shift, 3 bins are inadequate.

For purposes of computation, let us consider the period immediately after the 8 hours of packaging. At this time, at least 3 bins are filled or partially filled because of the 12 hours required in the bin drier. In addition to these 3 bins, 4 more are required to dry and store the product that will be produced during the coming 16 hours when no packaging is done. One additional bin must also be provided for use during the time the first bin is being emptied the following morning. Therefore it is obvious that at least 3 + 4 + 1 or 8 bins are required for this operation.

Little is known about drying rates of various vegetables in bin driers, but, as a basis for determining the approximate number of bins required, it is safe to assume that the retention time will be from 6 to 9 hours for an air velocity equivalent to 80 or 100 cubic feet of air per minute for each cross sectional square foot of active bin capacity. The maximum incoming air temperature should not exceed 10 degrees below that recommended for the dry-end temperature in a counterflow dehydrator for the same vegetable. It may be necessary with vegetables that are very sensitive to heat, to keep the temperature even lower than this.

If final results indicate that the capacity of the finishing unit is below the capacity expected, the operator need only increase the retention time in the preceding drying stages until a working balance is reached. This condition was illustrated by the previous example.

Air Desiccators

Bin drier operation will vary considerably between humid and arid regions. If high relative humidities are prevalent in the locality, it will be almost essential to employ some means of drying the air before it is introduced into the bin finisher. A unit for this purpose is called an air desiccator or air dehydrator. The former is the preferable designation, because the other may lead to confusion.

One of the most satisfactory means of drying air is through the use of a chemical adsorption or absorption drier. Units of this type are capable of delivering air at fairly high temperature and low absolute humidity. This method obviates the necessity of reheating the dehumidified air, as would be required by a dehumidifying unit using refrigeration. This factor may be of considerable importance in the selection of an air-desiccating method.

When an air desiccator is used with a bin finisher, it may become desirable to recirculate all or part of the drying air. In multi-bin operation, the air expelled from each bin will have a different absolute humidity, because the products in the bins are at various stages of dryness. In practice, however, the air from each bin is discharged into a common return duct. If the absolute humidity of the mixed air in the return duct is less than that of the outside air, then it should be recirculated; if not, it should be entirely wasted to atmosphere. On "borderline" installations this condition may vary from day to day; hence repeated daily checks should be made.

Sources of Heat

The air supply to bin driers is preferably heated by steam. Direct-fired units are not recommended, because the product may acquire a disagreeable taste from the flue gases. An open flame increases the fire and dust explosion hazards. The amount of heat required by a bin drier is relatively small; hence, the heat wasted by not recirculating it is negligible. The problem of recirculation should be decided on the basis of absolute humidity only, and not on the basis of heat.